



2003 AFCEE Technology Transfer Workshop

San Antonio, Texas

Promoting Readiness through Environmental Stewardship

Optimization at AFP06 Using Improved GTS

Kirk M. Cameron, Ph.D.
MacStat Consulting, Ltd.
24 February 2003



Air Force Real Property Agency



Basic Goal

- **Ensure adequate & sufficient data available to make good decisions**
 - May have redundant sampling information
 - Want to **minimize** waste; **maximize** usefulness of data collected
- **Optimization algorithm looks at two areas:**
 - Monitoring network locations
 - Sampling frequencies within network



Related Applications

- **Optimization of treatment systems**
 - **Example: sampling frequencies of influent/effluent for pump & treat operations**
- **Characterization & mapping of sites**
 - **Change in contaminant patterns over time**
 - **Hydrogeologic parameters needed for flow-based geophysical or fate/transport models**
 - **Subsurface mapping (bedrock, other strata)**
 - **Determining optimal locations for new sampling or drilling**



GTS Algorithm

- Designed with decision-logic framework
- Allows for separate identification of temporal & spatial redundancy
- Uses geostatistical and trend optimization methods
 - Variogram = spatial correlation measure
 - Kriging = spatial interpolation = spatial regression
 - Non-parametric linear regression
 - Locally-weighted regression

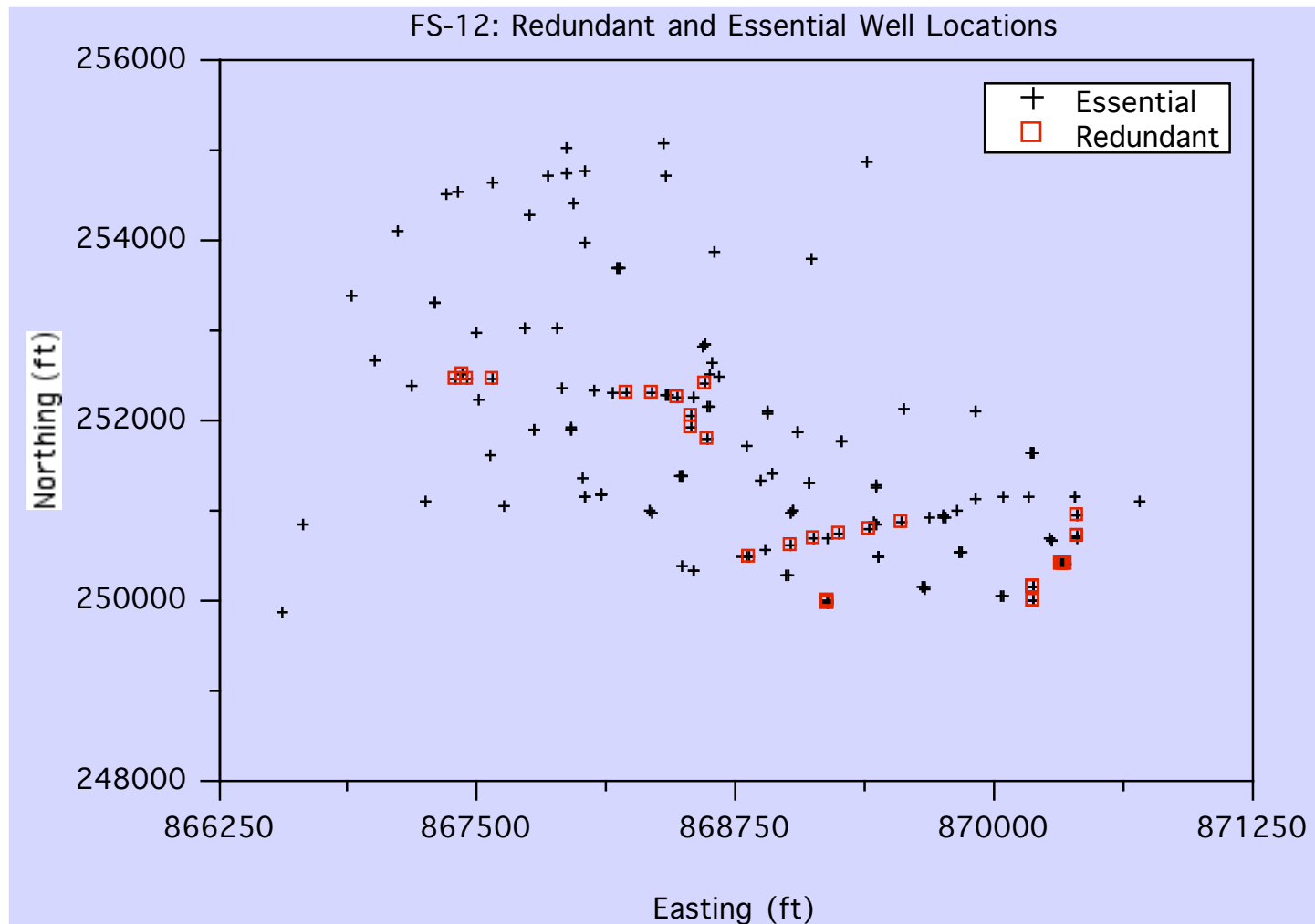


End-Products

- **Optimized sampling frequencies**
- **Identification of essential MW locations**
- **Typical reduction in sampling efforts/costs of 20-40%**



Identifying Redundant Wells



Promoting Readiness through Environmental Stewardship



Geostatistics at AFP06

- **AFP06**
 - 3 possibly interconnected plumes of TCE
 - B-4, B-10, B-90 sites
- **Challenges at Plant 6**
 - **Complex geologic/hydrogeologic environment**
 - Fractured geology
 - Uncertain hydraulic connectivity between subsurface horizons
 - **Poor spatial coverage in existing well network**
 - Bunching of wells along specific site features
 - Uneven 3-D coverage



Why Use GTS?

- **Must be able to rank well locations by spatial contribution to identify optimal networks**
 - **Other interpolators choose weights according to distance**
 - Inverse squared distance, triangulation, most contouring packages
 - Kriging uses spatial correlation model, incorporating spatial layout, distance, measurement correlations
- **Must also assess uncertainty**
 - Most popular interpolators do not or cannot
 - Kriging does
 - Can judge when optimal network is identified
 - Can determine level of statistical information contained in given network

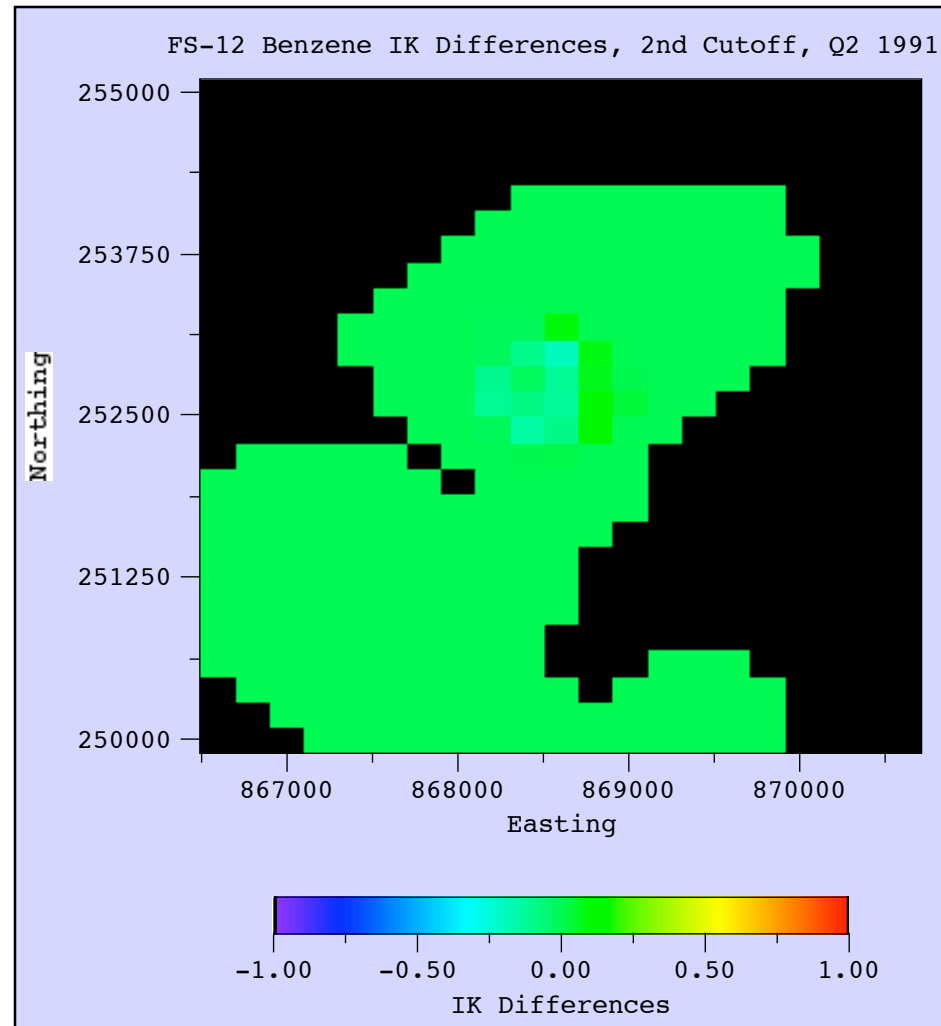


The GTS Advantage

- **Four separate measures used to assess spatial uncertainty/optimality**
 - **Net change in global variance**
 - **Net portion of site that becomes inestimable**
 - **Portion of site where net change in local variance exceeds threshold**
 - **Portion of site where net change in mapped concentration exceeds threshold**

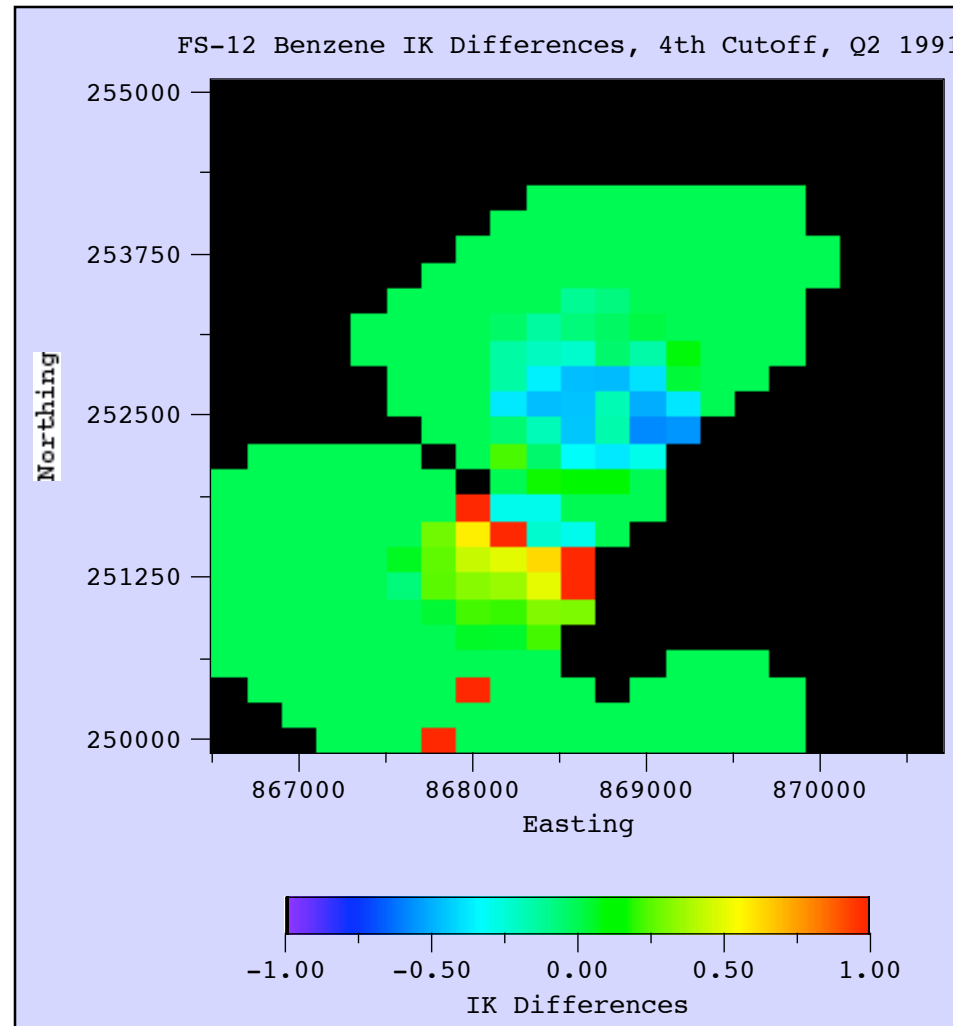


Kriging Differences: 2nd Cutoff



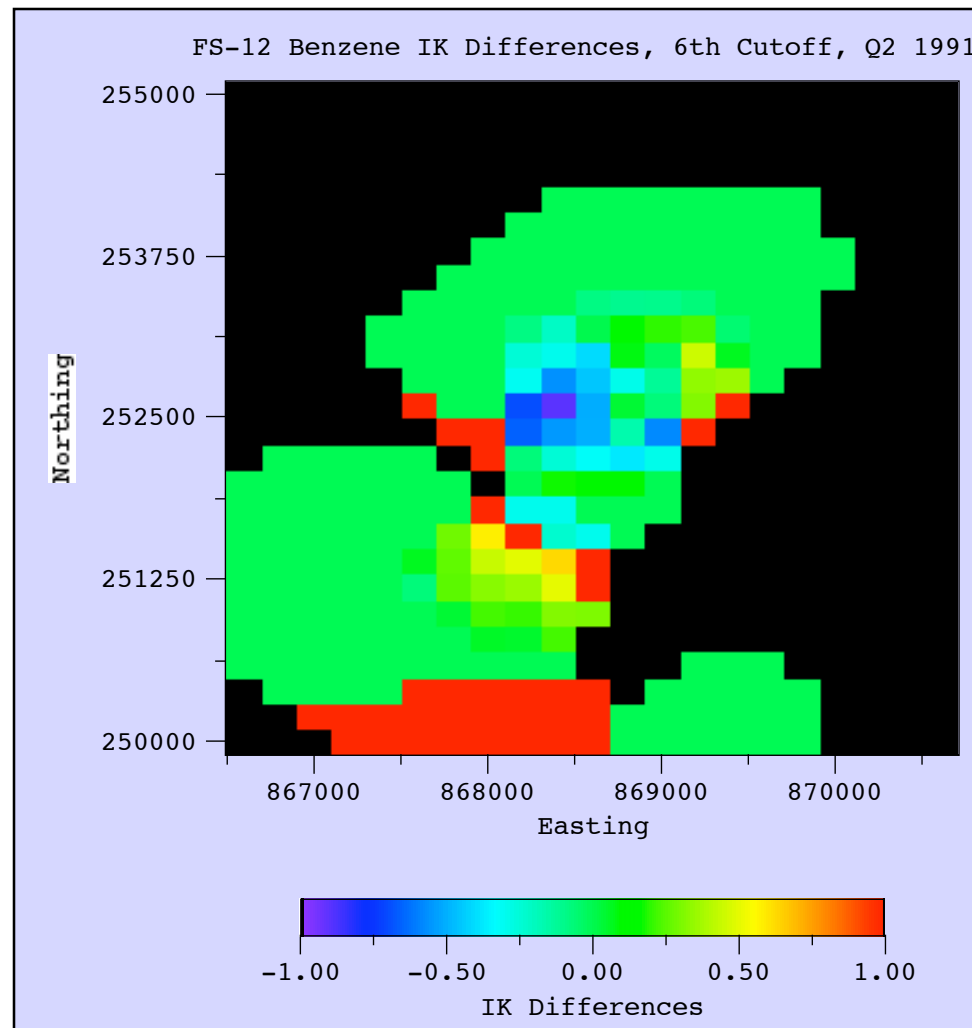


Kriging Differences: 4th Cutoff



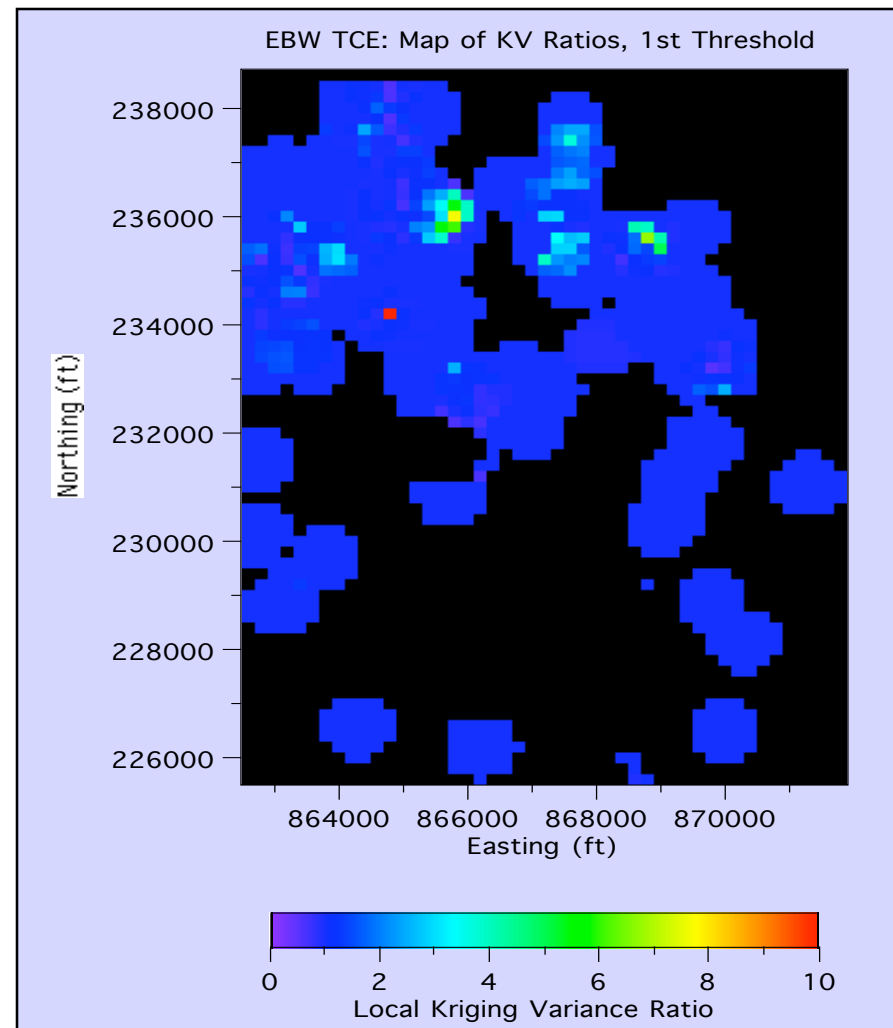


Kriging Differences: 6th Cutoff



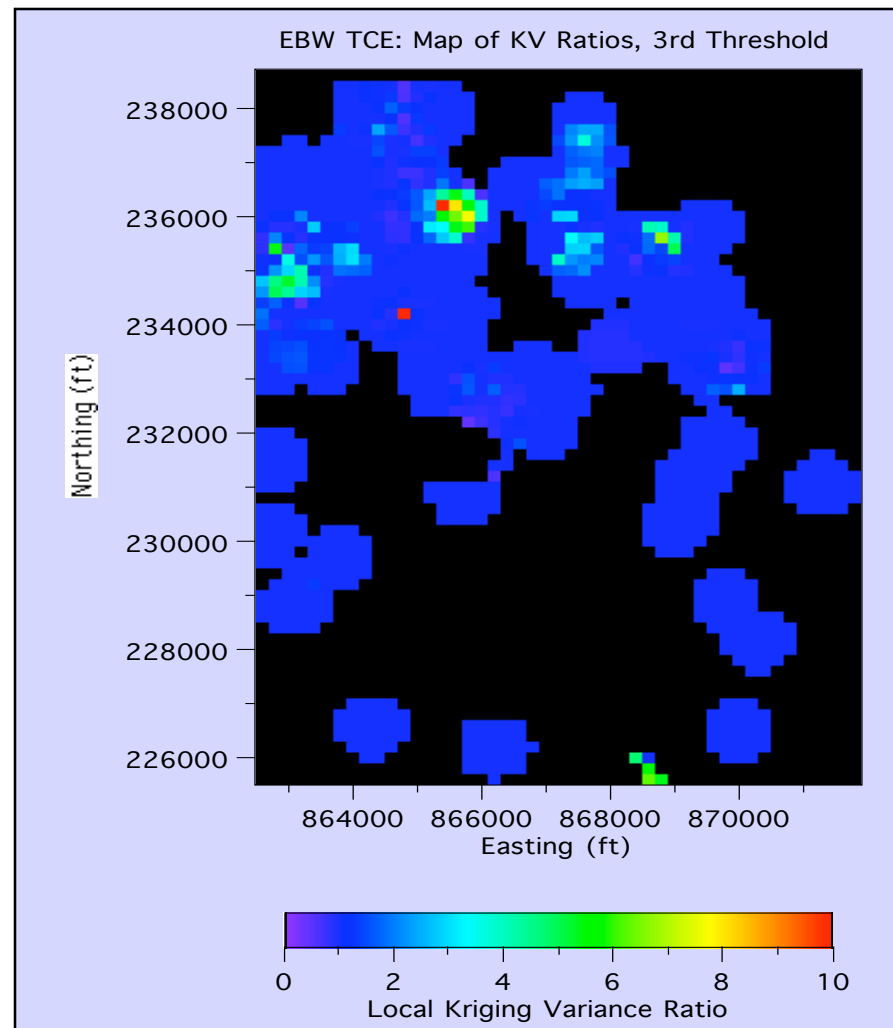


Local KV Ratios: 1st Cutoff



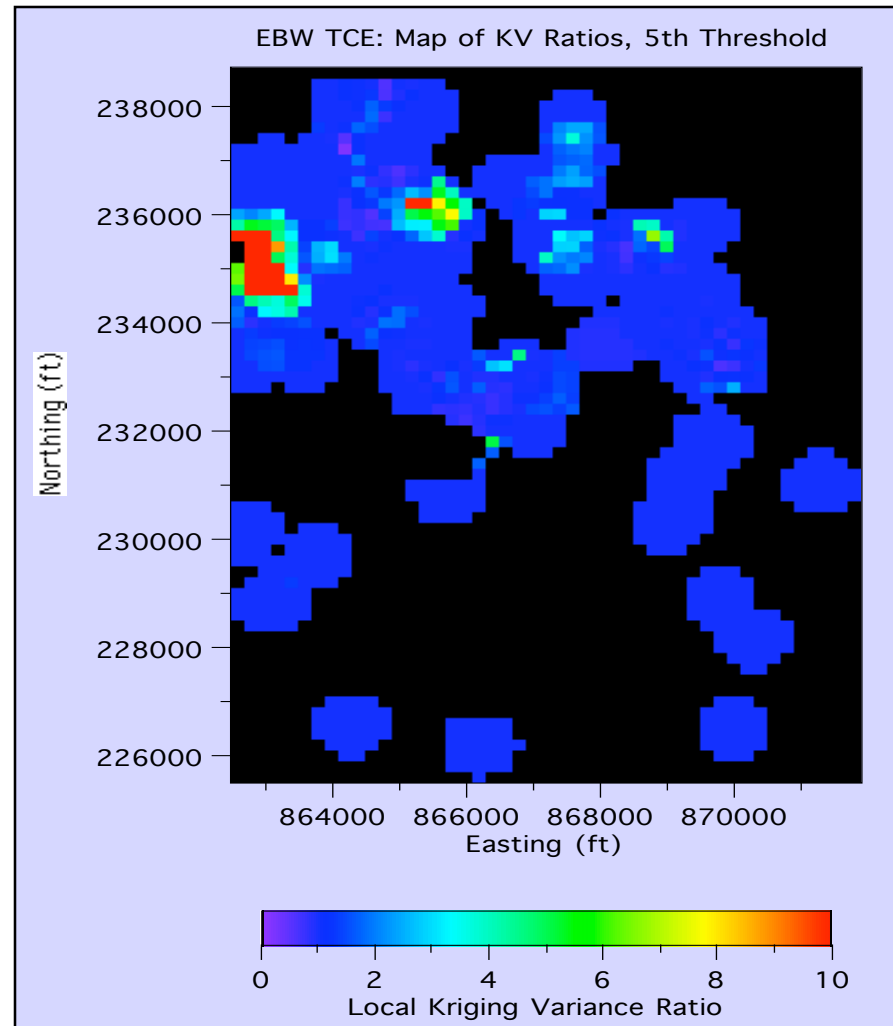


Local KV Ratios: 3rd Cutoff





Local KV Ratios: 5th Cutoff



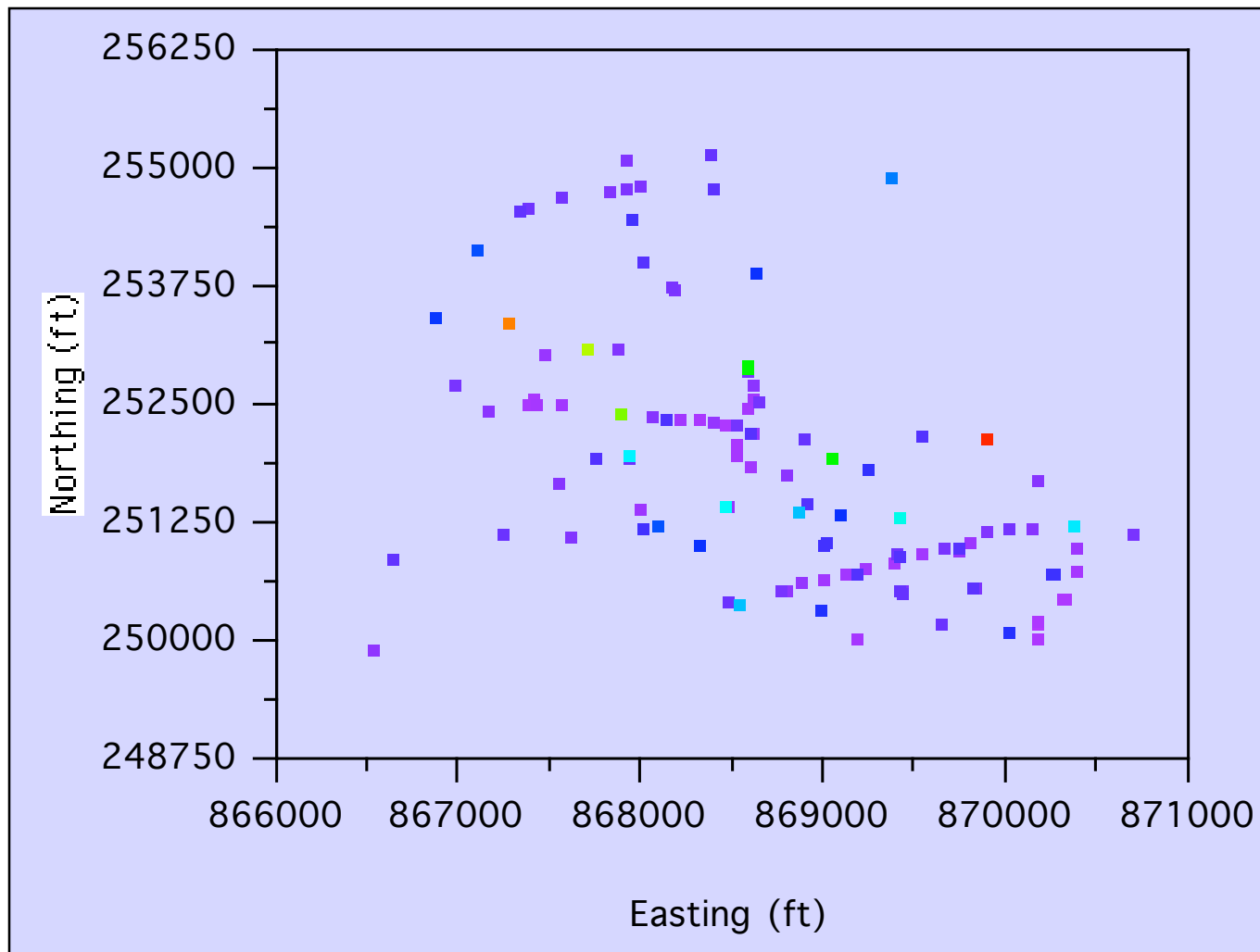


The GTS Advantage (cont)

- **Objective criteria for ranking well locations according to redundancy**
 - **Most subjectivity eliminated**



Example: Global Kriging Wgts





GTS Improvements

- **Estimating spatial correlation**
 - **Better spatial modeling**
- **Improved spatial regression**
 - **Probability Kriging**
 - **Alternate approach: locally-wgted regression**
- **Identifying optimal spatial networks**
 - **Testing new alternatives**
 - **Genetic algorithms**
 - **Using declustering wgts**
- **Improved temporal optimization**

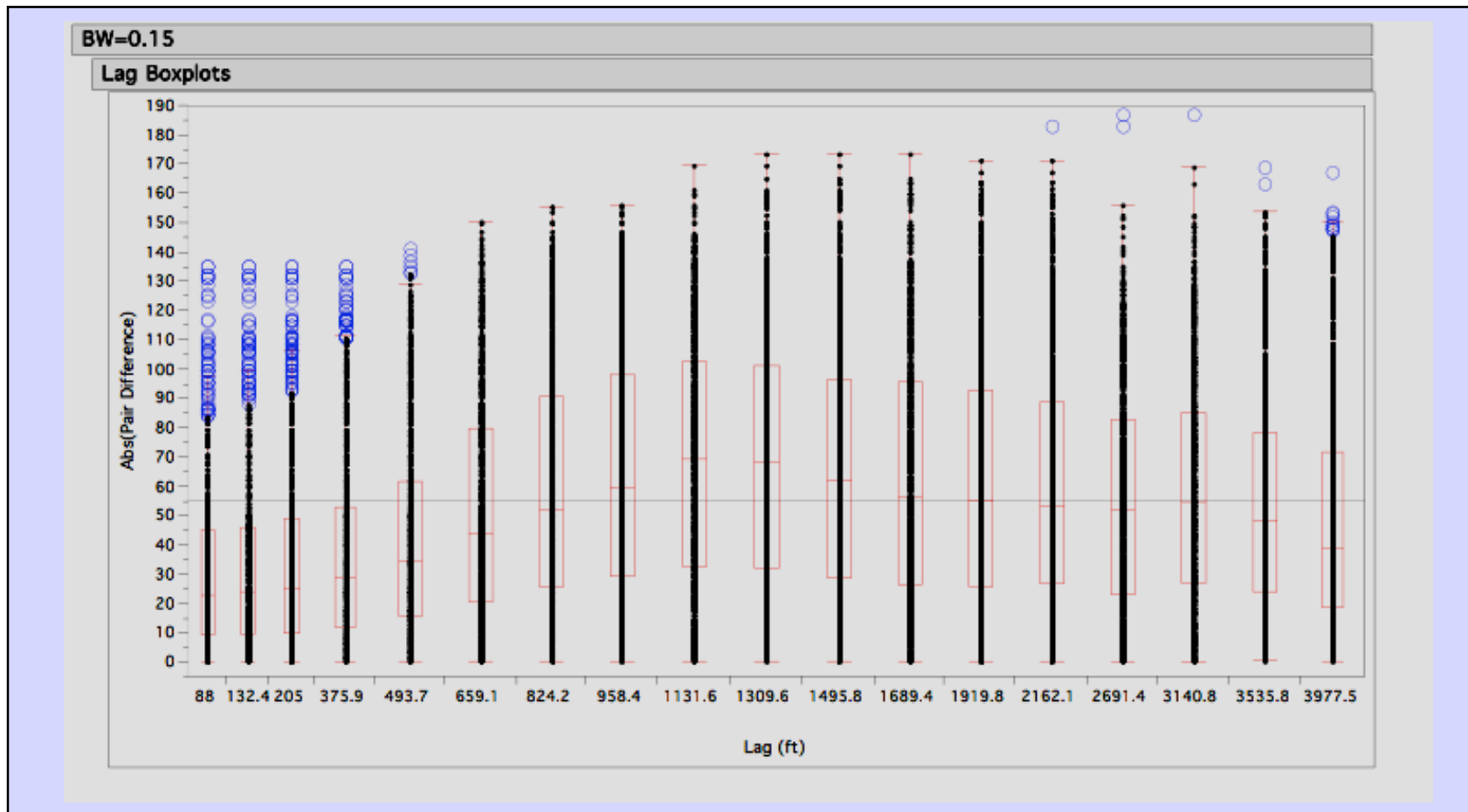


Modeling Spatial Correlation

- **Good correlation model drives spatial regression process**
 - **Avoid outliers**
 - **Find directions of anisotropy**
 - **Fit smooth models of correlation**
- **Dealing with variogram outliers**
 - **Exclude outliers from local nbhds of measurement pairs**
 - **Robust statistics used to fit/identify key variogram features**

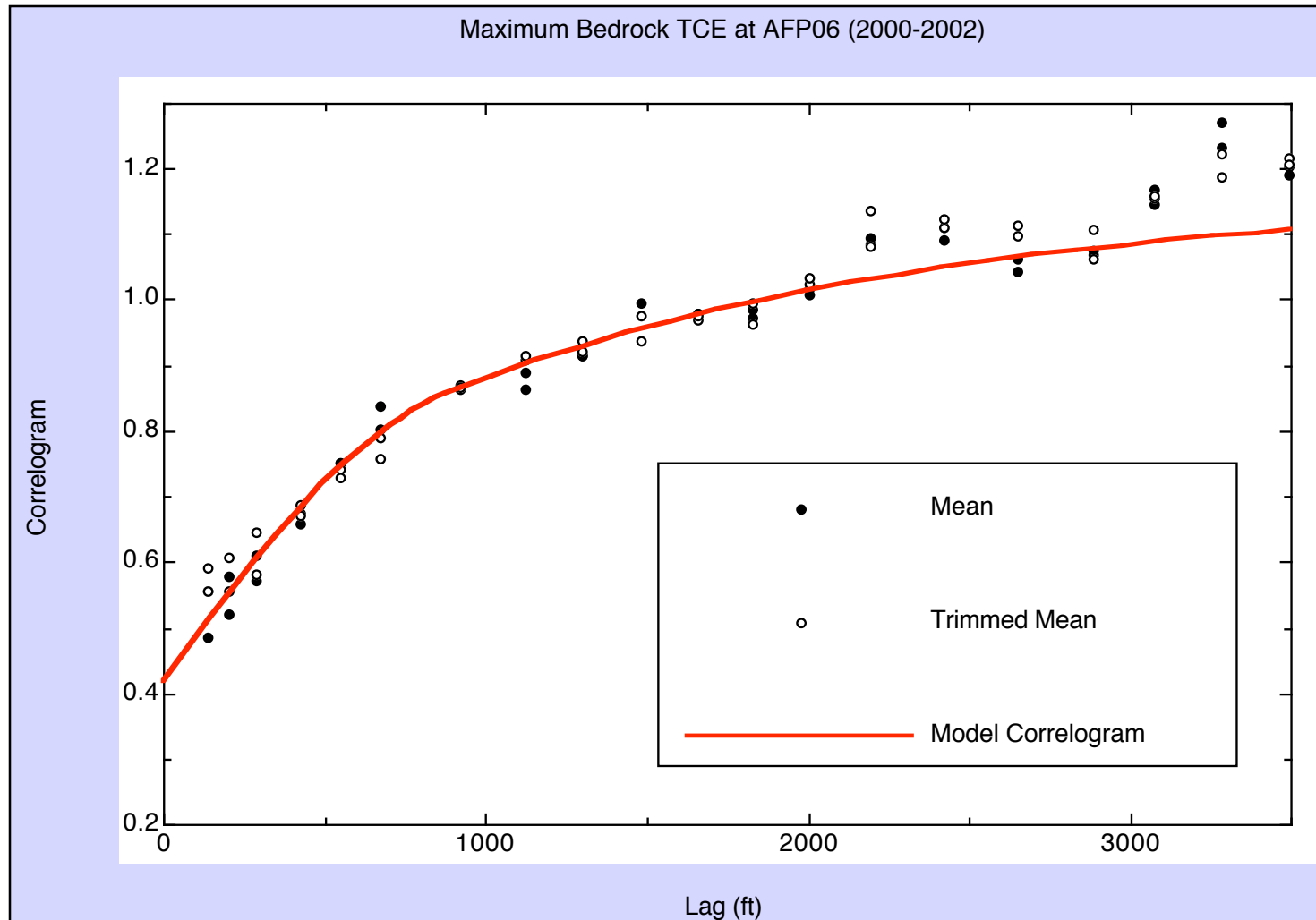


Minimizing Spatial Outliers





Robust Variograms



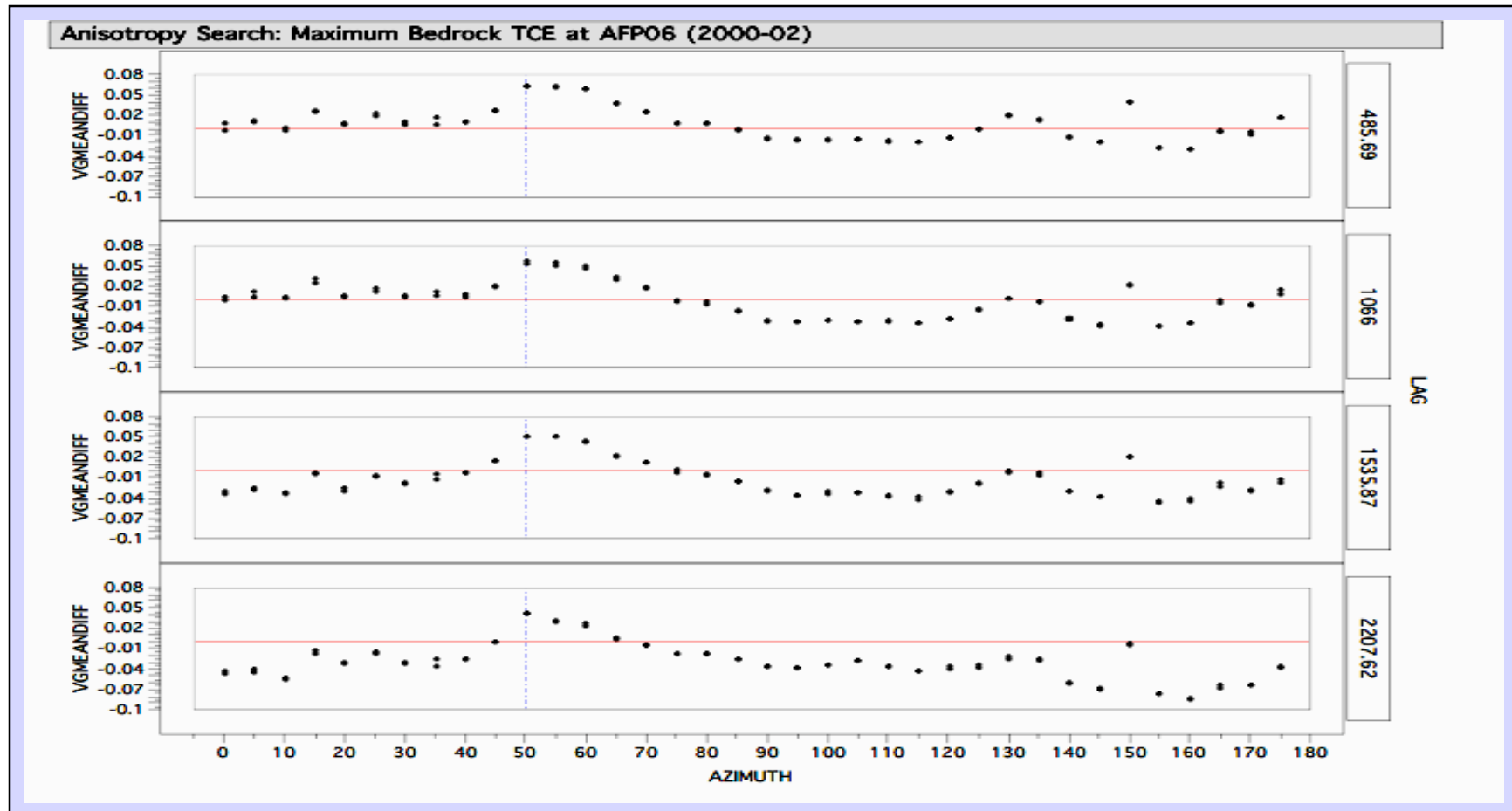


Finding Anisotropy

- **Anisotropy search routine**
 - **Plot variogram differences between major and minor axes for all planar orientations**
- **Variogram surfaces (2-D) and solids (3-D)**

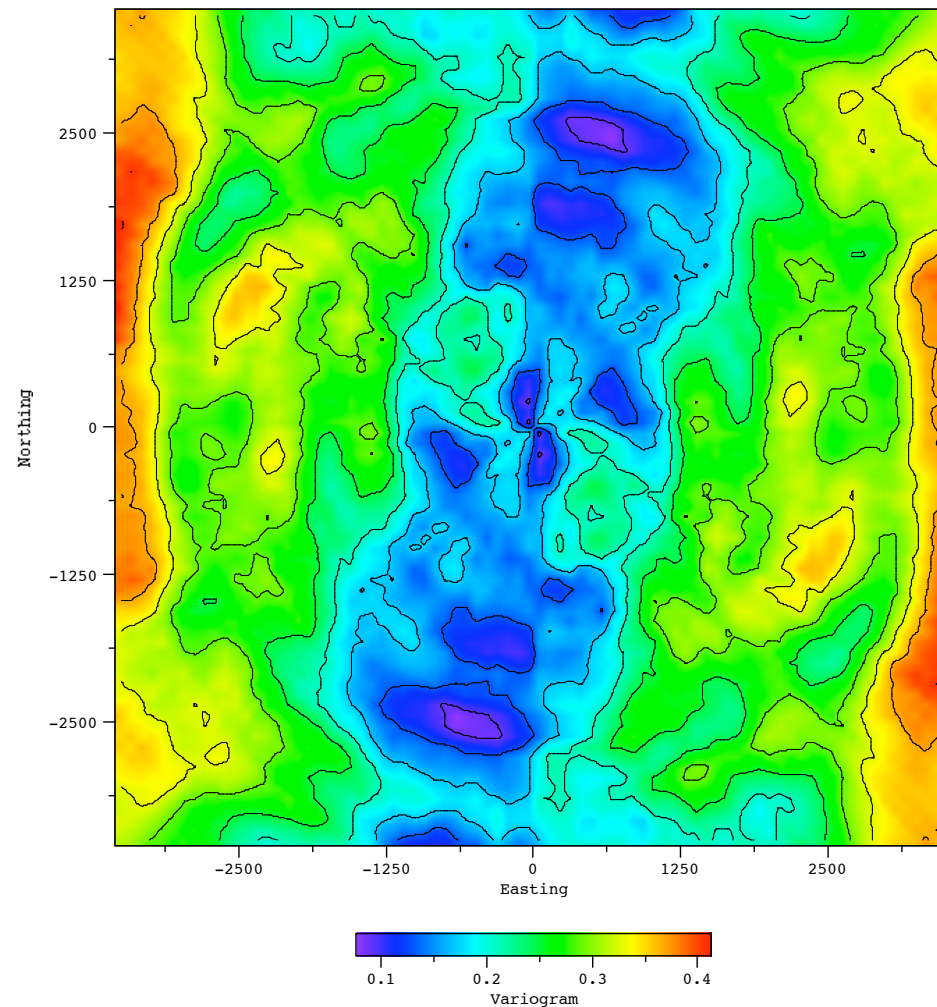


Anisotropy Search





Variogram Surface



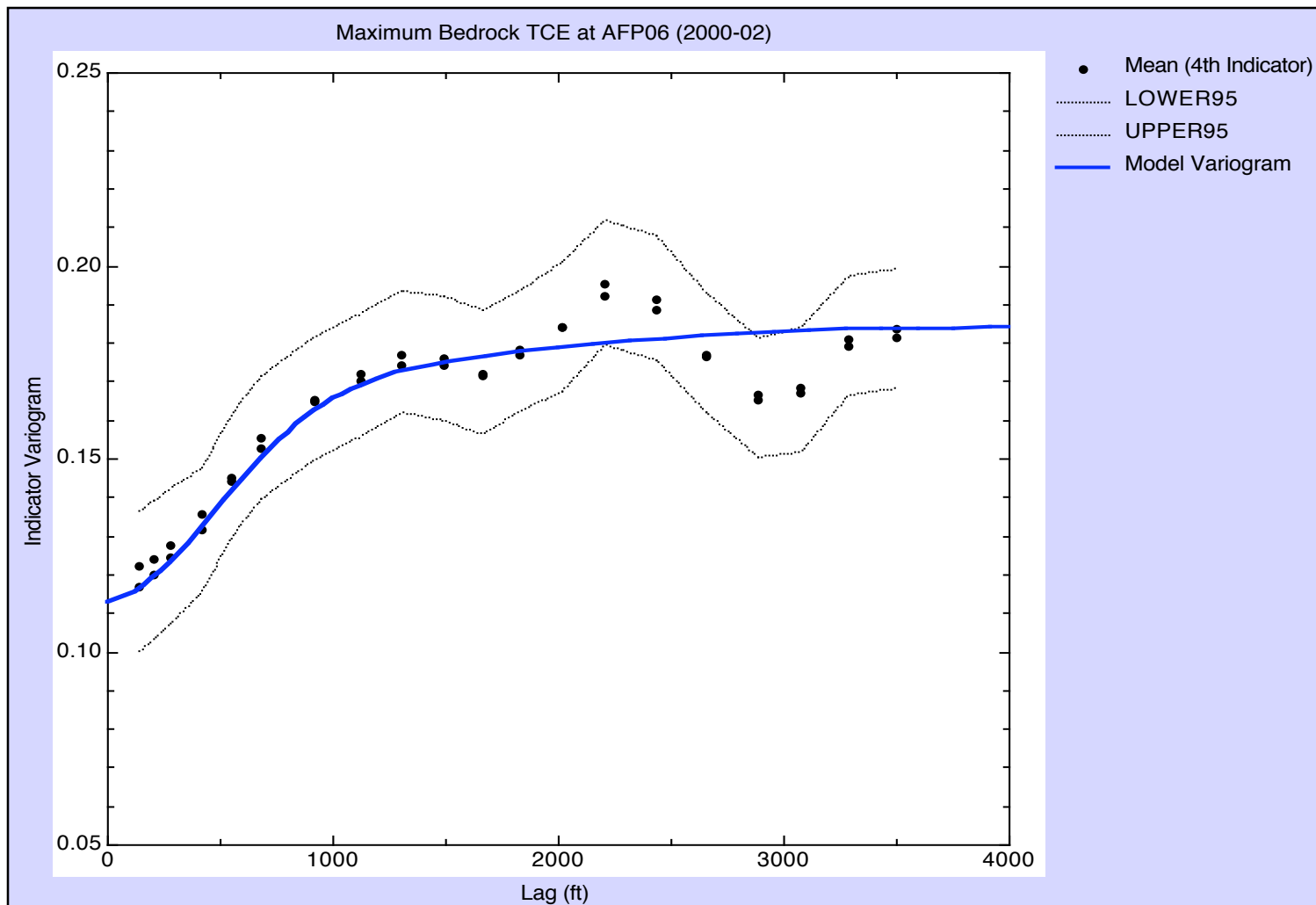


Fitting Smooth Models

- **Locally-weighted smoothing of empirical variograms**
 - **Moving windows**
 - **Weights decrease with pair distance from target lag**
- **Bootstrapped confidence bounds**



Smoother Variograms





Building Accurate Maps

- **Highly skewed measurement data often lead to skewed maps**
 - **Hard to identify smooth spatial correlation model with raw data**
- **Log-transform can lead to back-transform bias in kriged estimates**
- **Alternatives:**
 - **Probability kriging**
 - **Locally-weighted quadratic regression**



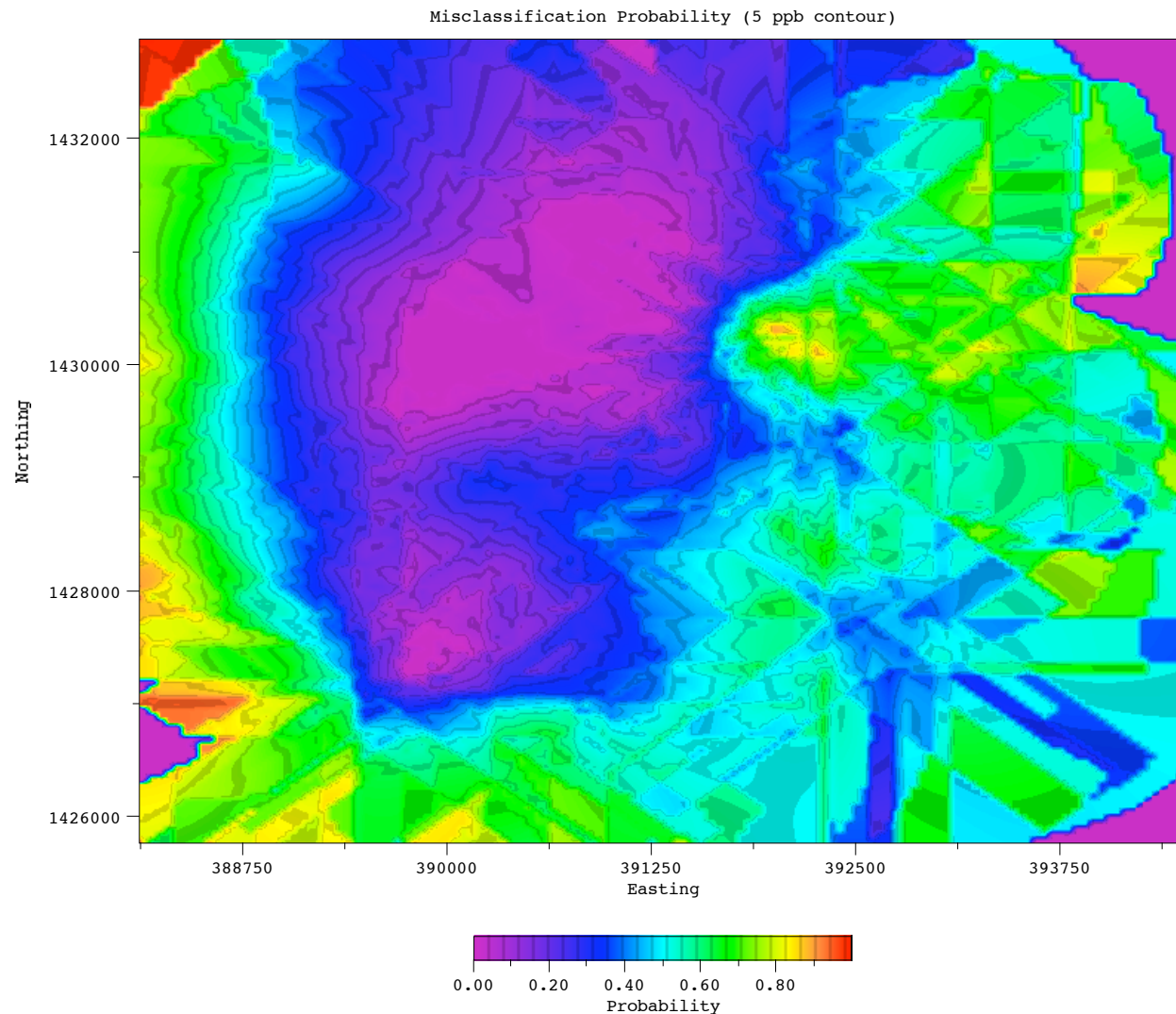
Probability Kriging

- **3-5 target contour levels**
 - Indicator values formed from data at each contour
 - Each indicator kriged in conjunction with uniform score transformation of original data
 - All values between 0 and 1
 - Indicators = probability of being below target contour
- **Conditional/updated distribution built at each pixel/voxel**
 - Can get direct estimates of mean, SD, conf intervals
- **Misclassification probabilities**
 - How likely that a pixel/voxel has been classified on wrong side of target contour?





Misclassification Map



Promoting Readiness through Environmental Stewardship



Locally-weighted Regression

- **Different assumptions from kriging**
 - Not an **interpolator**, but a **smoother**
 - **Uncorrelated errors**
 - Spatial correlation due to contours of underlying mean surface
- **Advantages**
 - No separate spatial modeling effort required
 - Multiple data pts per well allowed (e.g., multiple sampling dates)
 - Explicitly measures uncertainty based on data sparsity and local curvature of variable being mapped



Picking Optimal Networks

- **Current GTS approach**
 - Use global kriging wghts to rank well locations
 - Iteratively drop lowest contributors
 - Re-krig until too much spatial information lost
- **Alternatives:**
 - Genetic algorithms
 - Declustering weights



Alternatives

- **Declustering wghts**
 - **Usually used to identify more accurate distribution of variable of interest**
 - **Minimizes effect of spatial clustering**
 - **Can also be used to proportionately weight each data location, based on spatial correlation**
- **Declustering wghts can then replace global kriging wghts in identifying lowest contributors**
 - **Still must perform kriging to gauge loss of spatial information**



Genetic Algorithms

- **Candidate networks randomly generated, then evolved to select fittest choices**
 - **Mating, mutations**
 - **Fitness can be based on multiple criteria:**
 - **Cost of sampling**
 - **Minimum spatial variance**
- **Still requires spatial regression to evaluate fitness of any candidate network**
 - **Can be computationally intensive**



Temporal Optimization

- **Current GTS framework**
 - **Site-wide sampling frequencies**
 - Temporal, multi-well variogram
 - **Well-specific frequencies**
 - Non-parametric linear regression
 - Iterative thinning algorithm
 - Most useful for wells with roughly linear trend components
- **Alternative: locally-weighted regression**
 - Still close to non-parametric
 - Allows for complex trends & estimation of conf bnds
 - Can still use iterative thinning approach



Paid Advertisement

- Remember: the devil is always in the details
- If you want **quality** and **optimality** you can count on, don't settle for a GTS substitute
- Always use the real thing!
- GTS — the optimization **solution***

*Paid for by GTS Promotions, Inc